Understanding the Dynamics of Shallow-Water Oceanographic Moorings

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LONG-TERM GOALS

This project is part of a long-term scientific program to obtain a fundamental understanding of the dynamics of instrumented oceanographic buoy and cable systems. The motivation is driven by the needs of oceanographers to have reliable platforms that are capable of making ocean measurements anywhere in the world for extended periods of time.

OBJECTIVES

The objective is to improve our numerical techniques for predicting the dynamics of shallow-water oceanographic moorings by investigating two separate systems. The first system is an instrumented catenary surface mooring which has part of its mooring chain lying on the sea bottom. This is a standard configuration for deploying current meters along the Continental Margin where the water depth is less than 200 m. Specifically, we address the problem of the nonlinear interaction between the mooring line and the sea bottom. The results will be used to develop realistic boundary conditions that improve the stability of numerical simulations of slack shallow-water moorings during storm conditions. Present numerical simulations break down when the heave motion of the surface buoy becomes large.

The second system under investigation is a taut subsurface mooring made with compliant rope such as that used for deploying mines near beaches. We will verify the numerical simulation, developed at MIT, that predicts free-surface patterns due to buoy motion. Once the numerical code is verified, we will use the simulation together with wave data from the MISE experiment to predict actual free-surface patterns, which can be compared to radar signals.

APPROACH

Our approach in analyzing the bottom-interaction problem involves laboratory and full-scale experiments along with numerical simulations. The laboratory experiments involve a new servo-controlled, sea-state simulator that we have developed. It is capable of moving a 70-kilogram mass (cable plus attached masses) through a random, narrow-band motion profile equivalent to a real-life Sea State 3. The experimental set up consists of a mooring chain and attached masses configured with a section of the mooring line lying on the bottom. Instrumentation includes load cells at the buoy and anchor, video motion analysis for measuring the dynamics of the mooring line, and an array of miniature force sensors for measuring the impact force of the cable hitting the bottom. In conjunction

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with the laboratory experiments, we will deploy a shallow-water surface mooring at the Buoy Farm near Woods Hole, MA. The mooring will be instrumented for buoy motion, mooring line tension, and accelerations of the mooring line near the touchdown point. Wave data and current data will be collected with a SeaTex wave following buoy and a bottom mounted, upward looking acoustic doppler current profiler (ADCP). Based on the results of the laboratory experiment, we will settle on a model for the cable/bottom interaction. This could be one of the published models or a hybrid model is based on our experimental results. This will be incorporated into our numerical simulation of shallow water moorings. Final verification of the model will be obtained using the full-scale motion and tension data that we collected from the central mooring of the 1995-1996 Coastal Mixing and Optics Experiment.

The approach for the taut subsurface mooring involves laboratory experiments to test the accuracy of the simulated buoy motions and the free-surface patterns. In addition, we will use full-scale experiments to build on the motion data that we collected during the MISE experiment. We will perform the laboratory experiments at the MIT towing tank. We will moor a scale model of a taut subsurface buoy in the tank and generate waves with the wavemaker. We will then measure the motion of the cable and buoy, the tension in the cable, the fluid velocity around the buoy, and the shape of the free surface. The motion of the cable and buoy will be measured with a video camera in conjunction with a motion analyzer. The tension in the cable will be measured with a load cell. The fluid-velocity field will be measured using our particle imaging velocimetry system. The shape of the free surface just above the buoy will be visualized with a second camera in conjunction with an illuminated light spot on the free surface. Incident waves will be measured with wave gages. Full-scale experiments are planned to check the ability of the numerical simulations to predict the correct buoy motion and cable tension of a system with dimensions similar to those used for mines. These experiments will use the 0.6-meter diameter instrumented sphere developed for the MISE experiment. This buoy includes a six-axis motion package and a load cell for measuring tension. We will deploy the buoy at the Buoy Farm near Woods Hole, MA. We will use a similar set-up as described in Part A but with the bottom mounted ADCP profiler providing both the current velocity and wave spectra. We will use the data from the scale-model and full-scale experiments to make adjustments in the numerical codes. Once the experimental and numerical results are consistent, we can proceed to use the simulations with wave data from the MISE experiment to calculate the free-surface patterns at a given time. For the 19 hours of buoy motion data that was collected, we can compare the actual buoy response with the simulated response to verify that the cable dynamics are being simulated correctly.

WORK COMPLETED

Our numerical simulation, *WHOI Cable*, for analyzing 3-D statics and dynamics of oceanographic cable systems has been updated to Version 1.1, which improves the interface, fixes some minor programming bugs, and adds capabilities for handling multi-leg moorings. A user's manual has been published as a WHOI technical report (Gobat *et al*., 1997), and an article has been published describing different applications along with experimental verification (Gobat & Grosenbaugh, 1998).

Preparations have been made to deploy a slack shallow-water mooring at the Buoy Farm during the first week of December of this year. In-line accelerometer packages have been built and tested. They will be attached to the mooring chain near the bottom. We have arranged to borrow a 600 kHz acoustic doppler current profiler that will be mounted on the sea bottom. We have borrowed the SeaTex Waverider buoy from the Upper Ocean Processes Group at WHOI and prepared it for the

deployment. Our motion package has been programmed to sample tension and six-axis motion at 12.5 Hz for 20 minutes three times per day. The 5000-pound load cell has been calibrated and mounted in the buoy.

A test deployment of the taut mooring experimental set-up was made in August in Buzzards Bay. The MISE buoy and motion package were deployed in 14 m water depth along with a 1200 kHz acoustic doppler current profiler that measured current and wave spectra. The motion package recording system shut down before it was able to collect data. A software error was discovered and corrected. The test set-up will be deployed at the Buoy Farm experiment in spring 1999.

Analysis of the motion and tension data from the Coastal Mixing and Optics shallow-water mooring has been completed. We are in the processing of writing up the results, which are summarized below.

RESULTS

The most important result from the analysis of the tension and motion data from the Coastal Mixing and Optics mooring is the coupling between the static configuration and the dynamics. Mean tension is increased by the motion of the buoy. The buoy nearly follows the wave surface, but is out phase just enough to create a positive bias in the tension record. The mooring line itself acts as a second order spring so that the positive peaks are more extreme than the negative troughs. Under storm conditions, the tension record is biased upward by as much as 1300 N.

The dynamic tension increases with mean tension. The component of the tension in phase with the buoy motion is controlled by the spring stiffness and, more importantly, the mass of the mooring components that participate in the dynamics. As the mean tension increases, the spring stiffness increases due to a decrease in the mooring line curvature. At the same time, heavy bottom chain lifts off the sea bottom and is accelerated upward by the buoy motion. The overall effect is an increase of as much as 30% in the effective mass of the mooring (i.e., the constant the multiplies the buoy acceleration to produce in-phase tension). The out-of-phase component of tension is controlled by the drag of the instruments and mooring line. For large motion, there is a dramatic increase in the drag force to where is comparable to the in-phase inertial force. Again the drag constant (i.e., multiplies the square of the mooring line velocity to get out-of-phase tension) increases with mean tension. A simple model has been developed to predict mooring line tensions based on these results.

IMPACT/APPLICATIONS

The research on shallow-water moorings will provide improved understanding of the dynamics and lead to simple models for doing preliminary design analysis. Improved bottom boundary conditions will be integrated into our numerical codes for doing more sophisticated analysis of these types of systems. The results will use in the future for designing moorings that can last for many years without servicing. The research on taut elastic subsurface moorings will verify the MIT cable/buoy/free-surface simulation and lead to predictions of free-surface patterns during the MISE Experiment. The numerical tools that have been developed in support of both efforts can be applied to such varied systems as drifting cable systems, towed vehicle systems, oceanographic surface moorings, and multi-leg subsurface moorings.

TRANSITIONS

WHOI Cable is a complete engineering tool for performing static and dynamic analysis of oceanographic systems with cables. The code has a Windows-style interface that allows transition to other users. The program is being made available at no cost to the oceanographic research community. A list of projects and organizations that have used *WHOI Cable* are given in the next section.

RELATED PROJECTS

This is a list of funded research projects that have used *WHOI Cable* for dynamic analysis:

- AOSN Labrador Sea Docking Station (ONR)
- Horizontal Moored Array (ONR)
- Active Mooring (ONR)
- MISE Experiment (ONR-JHU)
- Eiger II Acoustic Array (Navy-JHU)
- Biomaper II (NSF)

This is a list of organizations that are currently using *WHOI Cable*:

- National Data Buoy Center (NOAA)
- Atlantic Oceanographic & Meteorological Lab (NOAA)
- Pacific Marine Engineering Laboratory (NOAA)
- Space & Naval Warfare Systems Command (SPAWAR)
- MIT Lincoln Laboratory
- Scripps Institute of Oceanography
- University of Washington (APL)
- Monterey Bay Aquarium Research Institute
- University of South Florida
- NATO SACLANT Research Center
- Enviroment Canada
- University of Victoria, British Columbia, Canada
- CSIRO Marine Research (Australia)
- National Data Buoy Center (India)

REFERENCES

J.I. Gobat and M.A. Grosenbaugh, 1998. "WHOI Cable: Time Domain Numerical Simulation of Moored and Towed Oceanographic Systems", *Proceedings of Oceans '98,* Nice, France.

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PUBLICATIONS

Gobat, J.I. and Grosenbaugh, M.A., 1998: “WHOI Cable: Time Domain Numerical Simulation of Moored and Towed Oceanographic Systems”, *Proceedings of Oceans ’98,* Nice, France.

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